UCRL 10179

University of California

Ernest O. Lawrence Radiation Laboratory

THE IMPURITY OF SCIENCE

Berkeley, California

UCRL-10179

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

THE IMPURITY OF SCIENCE

Melvin Calvin

April 19, 1962

Printed in USA. Price 50 cents. Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D.C.

UCRL-10179

THE IMPURITY OF SCIENCE*

Melvin Calvin

Department of Chemistry and Lawrence Radiation Laboratory**
University of California, Berkeley 4, California

Abstract

April 19, 1962

Science is impure in two ways. There is not a "pure" science. By this I mean that physics impinges on astronomy, on the one hand, and chemistry on biology on the other. And not only does each support its neighbors, but derives sustenance from them. The same can be said of chemistry. Biology is, perhaps, the example par excellence today of an "impure" science.

Beyond this, there is no "pure" science itself divorced from human values. The importance of science to the humanities and the humanities to science in their complementary contribution to the variety of human life grows daily. The need for men familiar with both is imperative. We are faced today with a social decision resulting from our progress in molecular genetics at least equal to, and probably greater than, that required of us twenty years ago with the maturity of nuclear power.

---

* Presented in the Robbins Lectures, Pomona College, Claremont, California, February 27, 1962.

** The preparation of this paper was sponsored by the U.S. Atomic Energy Commission.

THE IMPURITY OF SCIENCE

Melvin Calvin

I dare say that all of you at one time or another in the recent past have heard or read the term 'pure science' used in one context or another. This ubiquitous appearance of the word science itself in our daily lives to the degree that all of our high school seniors should not only have heard of science but should even have heard of the distinction implied by the adjective 'pure' is indicative of the importance that this area of human activity has come to occupy in modern society, certainly in western society. Some of the reasons for this are obvious and some are not so obvious, and both deserve some comment.

The most obvious, and best known, reason for this widespread appearance of the word science itself is, of course, the enormous impact that this area of human knowledge has had upon the physical conditions of life itself on the planet. This is largely by virtue of the technological by-products which have resulted (and which always result) from any newly discovered truth about the nature of the world around us. Here we come to one of the first and most apparent distinctions which give rise to the adjective 'pure' as it is applied to science and, by implication, its converse, which we have come to call applied science, or technology. While the advances of technology may and frequently do lead to what we call technological unemployment, the unexpected and unpredictable developments of pure science are the prime source of the entirely new industries which constantly rejuvenate our economy.

There are those who believe that not only does our modern science give rise to technology, but historically had its origin in man's physical needs and the ways he sought to fulfill them. Perhaps this may be true on the most primitive level. Man was cold and so he sought to make himself warm by various means such as creating the fire at will which occasionally he had seen happen accidentally. But I am sure that some men wondered about the nature of fire itself even before they could use it to keep themselves warm.

In more recent times, it appeared that the distinction between 'pure' and 'applied' was easier to make. There arose, with the birth of modern science some 300 or 400 years ago, a type of investigator who endeavored to explore the nature of the world around him in observable and testable terms solely because he was curious about it. For example, Leeuwenhoek was a lens grinder, and during the course of his manipulation of the lenses he found that he could see, with their help, objects invisible to the naked eye. This led him to produce better combinations of lenses and, ultimately, to his discovery of the whole micro-world of 'animalcules'. Galileo was looking in the other direction and wondered about the nature of the stars. This wonder led him not only to build his telescopes but to describe the new things he saw with them for others to see.

On the other hand, the applied arts, or technologies, were, in general, in the hands of quite a different group of men, the artisans and the engineers of the time, and so the distinction existed both in approach and in the men who did it. Daily that distinction is becoming less sharply defined, largely because we have explicitly recognized the nature of technology and have realized that its greatest successes are contained in the entirely new bits of truth about the world around us which the curiosity of man uncovers primarily to satisfy his need to understand.

Today discovery and its application do go hand in hand to such an extent that the popular impression most often does not distinguish between them, and the justification for the activities of the 'pure' scientist is most frequently sought in practical, or technological, terms. This is partly true, for example, in the justification of the expenditure of public funds for such activities; we will come back to this later.

Even within the sphere of 'pure' science alone there exists today an 'impurity' and a hybridization. Therein lies its strength. In the early days of the modern period it was probably possible for a single individual to encompass all of human knowledge, not only in the sciences but in the humanities and the arts as well. The term 'Renaissance Man' has often been used to describe such persons, and the implications of it are clear. As the extent of these activities increased there appeared a specialization. First the artist, the humanist and the scientist, or natural philosopher, were separated from each other, and then during the nineteenth and early twentieth centuries science itself, and by this I mean the so-called 'pure' science, was fragmented again. This was a necessary step for the collection of the enormous amount of detailed information on many subjects which had to take place in a systematic way. Only following such a collection could the generalizations about this knowledge be made. However, this fragmentation has been carried today to such an extent that men who all place themselves in the category of 'pure scientists' very commonly cannot speak each other's language. Thus the physicist studying the nuclei of atoms and the cytologist studying the nuclei of cells are likely to have only one word in common.

In fact, I would go even further than this and point to a meeting of the American Chemical Society at which there may be some 10,000 men gathered, attending hundreds of sessions. There will be among these men, all of whom call themselves chemists (and academic chemists at that), those who, when speaking on the frontiers of their particular area of interest, are incomprehensible to each other. For example, the geometry and stereospecificity of steroid chemistry will in its terms, concepts and language be very nearly totally incomprehensible to the kineticist studying the rates of reaction of triatomic molecules at gas pressures of one millibar. Similarly, the gas kineticist has a corresponding difficulty in communicating with the steroid biochemist. And they both call themselves chemists!

This situation was already recognized fifty years ago and very beautifully described in the 1911 Encyclopedia Britannica in an article under the heading 'Science' written by Sir William Cecil Dampier Wetham of Trinity College, Cambridge.

> 'In early times, when the knowledge of nature was small, little attempt was made to divide science into parts, and men of science did not specialize. Aristotle was a master of all science known in his day and wrote indifferently treatises on physics or animals. As increasing knowledge made it impossible for any one man to grasp all scientific subjects, lines of division were drawn for convenience of study and teaching. Besides the broad distinction into physical and biological science, minute subdivisions arose and at a certain stage of development much attention was given to methods of classification and much emphasis was laid on the results which were thought to have a significance beyond that of mere convenience of mankind. But we have reached the stage when the different streams of knowledge followed by the different sciences are coalescing and the artificial barriers raised by calling those sciences by different names are breaking down. Geology uses the methods and data of physics, chemistry and biology. No one can say whether sociology is properly grouped with biology or economics. Indeed it is often just where this coalescence of two subjects occurs, when some quick channel between them is opened suddenly, that the most striking advances in knowledge take place. The accumulated experience of one department of science and the

special methods which have been developed to deal with its problems become suddenly available in the domain of another department, and many questions unsolved before may find answers in the new light cast upon them. Such considerations show us that science is, in reality, one, although we may agree to look at it now from one side and now from another, as we approach it from the standpoint of physics, physiology or psychology.'

In spite of Sir William's recognition of the situation 50 years ago, things have gotten a lot worse before they appear to be getting better. The evidence for this is not only our own personal experience, but an additional objective statement in the form of an article which appeared entitled 'The Unification of Biology' by Professor C. D. Darlington at Oxford, which appeared in January of 1962 in The New Scientist and from which I would like to quote his appraisal of the situation. In describing the status of science today, in contrast to what it appeared to be even as late as 100 years ago, he says:

'....and an engineer, Herbert Spencer, was willing to expound every aspect of life, with an effect on his admiring readers which has not worn off today.

Things do not happen quite in this way nowadays. This, we are told, is an age of specialists. The pursuit of knowledge has become a profession. The time when a man could master several sciences is past. He must now, they say, put all his efforts into one subject. And presumably, he must get all his ideas from this one subject. The world, to be sure, needs men who will

> follow such a rule with enthusiasm. It needs the greatest numbers of the ablest technicians. But apart from them it also needs men who will converse and think and even work in more than one science and know how to combine or connect them. Such men, I believe, are still to be found today. They are still as glad to exchange ideas as they have been in the past. But we cannot say that our way of life is well-fitted to help them. Why is this?'

Apparently we have made very little progress in the last 50 years. In part, the reason lies in the unconscious entrenchment of vested interests of the scientific subdivisions that have grown up for purposes of convenience in the last century or two. That this separation is not an excluding accompaniment of the fine detail of the present-day scientific investigation is one of my theses. Combination and new synthesis is not only possible, but more necessary today than ever before.

Perhaps a good way to illustrate the importance of the interaction of what are now called the several independent and distinct branches of 'pure' science might best begin by a brief history of the development of our knowledge of the detailed mechanism of hereditary control in biology. It had long been recognized that the character of parents was in some way transmitted to their offspring, and this at all levels of life from viruses to man. The history of mankind shows a recognition of this in its social organizations, for example, hereditary monarchies.

which the nucleic acids control more subtle hereditary characteristics in microorganisms, for example, their dietary requirements or their virulence. This has gone so far that we must now call on the mathematician, information theorist and electrical engineer to help in the decoding of all the information contained in the hereditary tape which is the nucleic acid strand. Here you see the result of the collaboration and cooperation of practically every area of science, even overlapping into technology.

At first the progress along this route was slow and labored, partly because of the primitive status of our knowledge and partly because of the isolation of the different men involved. More recently, progress has accelerated and no small part of this acceleration has been due to the close physical and intellectual proximity of men who might have been, in an earlier time, isolated from each other, not only by space but by the classifications and subclassifications of 'pure' science.

Such interdisciplinary teamwork is being recognized as an important feature of most scientific work today. One element in the success of such teams is the more or less rapid transformation of the originally highly specialized ideas into more general conceptions, followed by the wide dissemination of these more general conceptions throughout the entire scientific community. This result is probably accomplished in a number of ways. The first and most obvious is the mutual stimulation of men working together and by continuous informal discussions gradually evolving, in the group as a whole, new notions and new developments which could hardly be attached to any one individual in the group. This is in contrast to the situation which obtains in work which does not overlap very much into two or more present-day areas of science. Here, the new development may more easily be attached to a single individual.

It is my feeling, however, that the synthesis of a really new conception which involves contributions from two or more distinct disciplines of science requires some sort of union in one mind of the pertinent aspects of several disciplines. The more of the various aspects of science which this man can and does truly encompass, the more likely is a new synthesis to be achieved. In order for this to take place, it is necessary that individuals be not afraid to undertake absorption of the knowledge in areas other than the one in which they were first trained.

This education must be such as to enable the young scientist to explore deeply and well some particular area of natural phenomena. There is no substitute for this sort of concentrated activity and concentration of thought. However, it must be accompanied by the conviction that the student is free to follow, and, in fact, has the duty to follow, the exploration of any natural phenomena into whatever area the light may lead him. In this way will the creation of new horizons overlapping existing divisions of science be encouraged. Without it, we will be limited to the classifications and subdivisions of science developed during the nineteenth and early twentieth centuries, and our thoughts, conceptions, and even practical developments will be circumscribed by the very words and modes of expression which each scientific subdivision of today tends to use.

While the internal walls within the house of science are slowly crumbling, here and there, so that the individual 'purities' are fading, assistance and reconstruction in this is required. This is only part of the much larger problem of bringing back together the various larger subdivisions of human knowledge, particularly of recognizing the place of science in the intellectual activity of man.

It is here that the greater 'impurity' lies. We have been prone to think of science primarily as the birthplace of technology and the child of human need. It is not uncommon to find individuals and organizations justifying their scientific activities in terms of its application, that is, its so-called 'practical' or technological values. We find this kind of justification made on two quite different, but related, levels.

For example, the popular writer for the newspapers and magazines in discussing with the scientific worker the nature of his discoveries will invariably seek to find what he calls the 'useful' application of this discovery, and by 'useful' he means: How can it be utilized to increase the physical ease of the human environment? He is convinced that his readers, that is, the popular readers, have this uppermost in their minds and will read only those stories which contain some elements of material comfort in them. The other level which is based on a similar conviction is that our public legislators from whom a very large fraction of the money to support scientific activities must now come, are moved only by the 'practical' values that they might directly see as a result of their appropriations.

In both these conceptions, the protagonists have overlooked the fact that it has been the great new truths resulting from the activities of scientists as curious human beings that have produced the great transformations which have taken place in the last half dozen centuries in man's view of himself and his place in the universe. Keppler's concern to understand the motion of the heavenly bodies led him to follow Copernicus in putting the sun in the center of our immediate region of space. The earth then became one of the smaller bodies rotating about it, and thus man's home was finally displaced from its central position in the heavens which it had long occupied. This contributed to a profound change in man's concept of his place. Darwin's formulation of evolution in terms of natural selection again placed man in a new relation to life itself which has significantly affected all of his thinking and is still one of the central themes influencing not only the philosophers but the practical politicians as well, not to mention the scientists themselves!

I have selected only two of the most obvious and oustanding scientific truths which have had the most profound and direct influence on our daily intellectual lives. This is continuing today in many small as well as large ways. For example, our knowledge of the mechanism of brain structure and function on all levels, including the molecular, is increasing. I have no doubt but what this will have a profound effect upon our present concept of what the nature of consciousness and self-consciousness really is. And this has not yet mentioned what the so-called 'practical' effect of such knowledge might be in the form of either new machines, or the manipulation of man's mind.

Perhaps the most immediate and pressing example of an iminent scientific development whose various effects on our lives can at least be imagined is the impending detailed knowledge of the molecular basis of heredity which we will soon have. In fact, we already have a good deal of it. By this I mean we already know a good deal about the way in which information concerning the construction of a living organism is handed on from generation to generation on a molecular level.

We are fairly confident that this information is in the form of a linear array of only four letters, strung along as though they were on a tape. The whole message for a living organism will be billions of letters long, depending on the complexity of the organism. We can already take fragments of these tapes from one type of an organism and use them to transform another type. We are about to learn how to read the individual letters of these fragments for their smallest bits and pieces of information.

We will shortly be able to use pre-formed bits of this tape, suitably chosen, to control virus infection. Very likely a similar process will be involved in the control ofthe cellular genetic accidents which give rise to cander. It will not be long before we will be able to repair by this means congenital metabolic accidents which at present we are helpless to treat. One can foresee the time when fragments of these information-bearing tapes (the DNA or RNA fragments) will be susceptible to laboratory synthesis.

I think it is clear that we will in the not too distant future be able to 'tamper' with the hereditary mechanism, not only for the primitive microorgansisms but for more highly developed organisms as well, and how we 'tamper' will be a matter of grave concern to us all. Both the immediate and long range future of our country and of mankind is dependent upon decisions on the way we use the fruits of this new knowledge.

If mankind is to survive, the men who make these decisions must be men of broad background. As the chemist must now combine knowledge in fields other than his own, so also must the statesman, businessman and the individual citizen combine basic understanding of science with the humanistic areas of knowledge. The need is pressing and immediate, for we have before us now the requirement for a decision on a course of action probably more profound and far reaching in its consequences than that which faced the statesmen of the world following the discovery of nuclear fission in 1939 and the creation of the first nuclear explosives only six years later. The 'privilege' of 'tampering with heredity' is about to be given to us.

While we cannot predict at this stage the precise nature of the political and social consequences of such changes, that such changes will be profound I have no doubt, and we must be prepared for them on the broadest possible base. Along with scientific specializations, the myth has grown that only a scientist can understand science, and that only children who show promise of becoming scientists need be trained in the fundamental knowledge of science. But only consider for a moment the future of your own progeny if the knowledge made available by science is written into law by legislators who have no way of understanding the implications of that which they legislate.

Only consider the dilemma of the statesmen who were forced to make the initial decisions regarding the first atomic bomb. The scientists who developed the technical information which led to the production of the bomb were forced into sociological decisions of the implication of the use of this new scientific knowledge. The statesmen, equally, were forced into basic, if elementary, understanding of the nature of this new power. The discussions of implications from both the scientific and humanitarian view have occupied world attention for the past twenty-five years.

Let us suppose, for example, that certain legislation concerning an elementary human need is under consideration. During the course of that consideration, the announcement appears that all men born in the west will henceforth have purple eyes if that legislation is enacted. What, then, would be the effect on the legislative decision of such an announcement? Purposely, of course, the example is ludicrous, but one may extrapolate into other areas.

Thus, it is apparent that for the welfare of mankind, scientists must understand the basic knowledge of other fields than their own, and, in addition, must understand the world about them in terms of the humanist as well. And, conversely, the student of the humanities must understand the interrelationships of his own specialty (for example, of urban planning, with the humanitarian, or aesthetic, provisions for peace of mind and of environment) as well as the relationship of his specialty to new knowledge advanced in the area of science.

This is another of the facets of the justification that science must be returned to its proper place as one of the essential components of a liberal education together with the humanistic, aesthetic and literary arts. And in the final analysis science is in the curriculum because it constitutes one of the three or four principal ways that mankind has evolved, up til now, of taking a view of the world around him.

SUMMARY

Once, to many scholars, 'pure' science was the Elysian field, where a biologist could safely spend his lifetime untouched by the physicist, or the chemist. This was true for each branch of natural human knowledge, and this was necessary for the detailed exploration and description of our world. Now so much has been learned in so many artificially defined areas of knowledge that the chemist may not spend his life studying 'pure chemistry' but must be influenced in the comprehension of any problem by the knowledge amassed by the physical scientist, on the one hand, and the biologist, on the other.

A greater impurity, however, lies in the fact that science is not only the birthplace of technology and the child of human need but also a prime progenitor of the great transformations in man's view of himself and his place in the universe which have taken place in the last half dozen centuries and which are due for even greater transformation. Both the immediate and the long range future of our country and of mankind is dependent upon decisions of how we use the fruits of this changing knowledge.

If mankind is to survive, the men who make these decisions must be men of broad background. As the chemist must now combine the knowledge in fields other than his own, so also must the statesman, the businessman, and the individual citizen combine basic understanding of science with the humanistic areas of knowledge. The need is pressing and immediate, for we have before us now the requirement for a decision on a course of action probably more profound and far reaching in its consequences than that which faced the statesmen of the world following the discovery of nuclear fission in 1939 and the creation of the first nuclear explosives only six years later. The 'privilege' of 'tampering with heredity' is about to be given to us.

University of California

Ernest O. Lawrence Radiation Laboratory

THE IMPURITY OF SCIENCE

Berkeley, California

UCRL-10179

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

THE IMPURITY OF SCIENCE

Melvin Calvin

April 19, 1962

Printed in USA. Price 50 cents. Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D.C.

UCRL-10179

THE IMPURITY OF SCIENCE*

Melvin Calvin

Department of Chemistry and Lawrence Radiation Laboratory**
University of California, Berkeley 4, California

Abstract

April 19, 1962

Science is impure in two ways. There is not a "pure" science. By this I mean that physics impinges on astronomy, on the one hand, and chemistry on biology on the other. And not only does each support its neighbors, but derives sustenance from them. The same can be said of chemistry. Biology is, perhaps, the example par excellence today of an "impure" science.

Beyond this, there is no "pure" science itself divorced from human values. The importance of science to the humanities and the humanities to science in their complementary contribution to the variety of human life grows daily. The need for men familiar with both is imperative. We are faced today with a social decision resulting from our progress in molecular genetics at least equal to, and probably greater than, that required of us twenty years ago with the maturity of nuclear power.

---

* Presented in the Robbins Lectures, Pomona College, Claremont, California, February 27, 1962.

** The preparation of this paper was sponsored by the U.S. Atomic Energy Commission.

THE IMPURITY OF SCIENCE

Melvin Calvin

I dare say that all of you at one time or another in the recent past have heard or read the term 'pure science' used in one context or another. This ubiquitous appearance of the word science itself in our daily lives to the degree that all of our high school seniors should not only have heard of science but should even have heard of the distinction implied by the adjective 'pure' is indicative of the importance that this area of human activity has come to occupy in modern society, certainly in western society. Some of the reasons for this are obvious and some are not so obvious, and both deserve some comment.

The most obvious, and best known, reason for this widespread appearance of the word science itself is, of course, the enormous impact that this area of human knowledge has had upon the physical conditions of life itself on the planet. This is largely by virtue of the technological by-products which have resulted (and which always result) from any newly discovered truth about the nature of the world around us. Here we come to one of the first and most apparent distinctions which give rise to the adjective 'pure' as it is applied to science and, by implication, its converse, which we have come to call applied science, or technology. While the advances of technology may and frequently do lead to what we call technological unemployment, the unexpected and unpredictable developments of pure science are the prime source of the entirely new industries which constantly rejuvenate our economy.

There are those who believe that not only does our modern science give rise to technology, but historically had its origin in man's physical needs and the ways he sought to fulfill them. Perhaps this may be true on the most primitive level. Man was cold and so he sought to make himself warm by various means such as creating the fire at will which occasionally he had seen happen accidentally. But I am sure that some men wondered about the nature of fire itself even before they could use it to keep themselves warm.

In more recent times, it appeared that the distinction between 'pure' and 'applied' was easier to make. There arose, with the birth of modern science some 300 or 400 years ago, a type of investigator who endeavored to explore the nature of the world around him in observable and testable terms solely because he was curious about it. For example, Leeuwenhoek was a lens grinder, and during the course of his manipulation of the lenses he found that he could see, with their help, objects invisible to the naked eye. This led him to produce better combinations of lenses and, ultimately, to his discovery of the whole micro-world of 'animalcules'. Galileo was looking in the other direction and wondered about the nature of the stars. This wonder led him not only to build his telescopes but to describe the new things he saw with them for others to see.

On the other hand, the applied arts, or technologies, were, in general, in the hands of quite a different group of men, the artisans and the engineers of the time, and so the distinction existed both in approach and in the men who did it. Daily that distinction is becoming less sharply defined, largely because we have explicitly recognized the nature of technology and have realized that its greatest successes are contained in the entirely new bits of truth about the world around us which the curiosity of man uncovers primarily to satisfy his need to understand.

Today discovery and its application do go hand in hand to such an extent that the popular impression most often does not distinguish between them, and the justification for the activities of the 'pure' scientist is most frequently sought in practical, or technological, terms. This is partly true, for example, in the justification of the expenditure of public funds for such activities; we will come back to this later.

Even within the sphere of 'pure' science alone there exists today an 'impurity' and a hybridization. Therein lies its strength. In the early days of the modern period it was probably possible for a single individual to encompass all of human knowledge, not only in the sciences but in the humanities and the arts as well. The term 'Renaissance Man' has often been used to describe such persons, and the implications of it are clear. As the extent of these activities increased there appeared a specialization. First the artist, the humanist and the scientist, or natural philosopher, were separated from each other, and then during the nineteenth and early twentieth centuries science itself, and by this I mean the so-called 'pure' science, was fragmented again. This was a necessary step for the collection of the enormous amount of detailed information on many subjects which had to take place in a systematic way. Only following such a collection could the generalizations about this knowledge be made. However, this fragmentation has been carried today to such an extent that men who all place themselves in the category of 'pure scientists' very commonly cannot speak each other's language. Thus the physicist studying the nuclei of atoms and the cytologist studying the nuclei of cells are likely to have only one word in common.

In fact, I would go even further than this and point to a meeting of the American Chemical Society at which there may be some 10,000 men gathered, attending hundreds of sessions. There will be among these men, all of whom call themselves chemists (and academic chemists at that), those who, when speaking on the frontiers of their particular area of interest, are incomprehensible to each other. For example, the geometry and stereospecificity of steroid chemistry will in its terms, concepts and language be very nearly totally incomprehensible to the kineticist studying the rates of reaction of triatomic molecules at gas pressures of one millibar. Similarly, the gas kineticist has a corresponding difficulty in communicating with the steroid biochemist. And they both call themselves chemists!

This situation was already recognized fifty years ago and very beautifully described in the 1911 Encyclopedia Britannica in an article under the heading 'Science' written by Sir William Cecil Dampier Wetham of Trinity College, Cambridge.

> 'In early times, when the knowledge of nature was small, little attempt was made to divide science into parts, and men of science did not specialize. Aristotle was a master of all science known in his day and wrote indifferently treatises on physics or animals. As increasing knowledge made it impossible for any one man to grasp all scientific subjects, lines of division were drawn for convenience of study and teaching. Besides the broad distinction into physical and biological science, minute subdivisions arose and at a certain stage of development much attention was given to methods of classification and much emphasis was laid on the results which were thought to have a significance beyond that of mere convenience of mankind. But we have reached the stage when the different streams of knowledge followed by the different sciences are coalescing and the artificial barriers raised by calling those sciences by different names are breaking down. Geology uses the methods and data of physics, chemistry and biology. No one can say whether sociology is properly grouped with biology or economics. Indeed it is often just where this coalescence of two subjects occurs, when some quick channel between them is opened suddenly, that the most striking advances in knowledge take place. The accumulated experience of one department of science and the

special methods which have been developed to deal with its problems become suddenly available in the domain of another department, and many questions unsolved before may find answers in the new light cast upon them. Such considerations show us that science is, in reality, one, although we may agree to look at it now from one side and now from another, as we approach it from the standpoint of physics, physiology or psychology.'

In spite of Sir William's recognition of the situation 50 years ago, things have gotten a lot worse before they appear to be getting better. The evidence for this is not only our own personal experience, but an additional objective statement in the form of an article which appeared entitled 'The Unification of Biology' by Professor C. D. Darlington at Oxford, which appeared in January of 1962 in The New Scientist and from which I would like to quote his appraisal of the situation. In describing the status of science today, in contrast to what it appeared to be even as late as 100 years ago, he says:

'....and an engineer, Herbert Spencer, was willing to expound every aspect of life, with an effect on his admiring readers which has not worn off today.

Things do not happen quite in this way nowadays. This, we are told, is an age of specialists. The pursuit of knowledge has become a profession. The time when a man could master several sciences is past. He must now, they say, put all his efforts into one subject. And presumably, he must get all his ideas from this one subject. The world, to be sure, needs men who will

> follow such a rule with enthusiasm. It needs the greatest numbers of the ablest technicians. But apart from them it also needs men who will converse and think and even work in more than one science and know how to combine or connect them. Such men, I believe, are still to be found today. They are still as glad to exchange ideas as they have been in the past. But we cannot say that our way of life is well-fitted to help them. Why is this?'

Apparently we have made very little progress in the last 50 years. In part, the reason lies in the unconscious entrenchment of vested interests of the scientific subdivisions that have grown up for purposes of convenience in the last century or two. That this separation is not an excluding accompaniment of the fine detail of the present-day scientific investigation is one of my theses. Combination and new synthesis is not only possible, but more necessary today than ever before.

Perhaps a good way to illustrate the importance of the interaction of what are now called the several independent and distinct branches of 'pure' science might best begin by a brief history of the development of our knowledge of the detailed mechanism of hereditary control in biology. It had long been recognized that the character of parents was in some way transmitted to their offspring, and this at all levels of life from viruses to man. The history of mankind shows a recognition of this in its social organizations, for example, hereditary monarchies.

which the nucleic acids control more subtle hereditary characteristics in microorganisms, for example, their dietary requirements or their virulence. This has gone so far that we must now call on the mathematician, information theorist and electrical engineer to help in the decoding of all the information contained in the hereditary tape which is the nucleic acid strand. Here you see the result of the collaboration and cooperation of practically every area of science, even overlapping into technology.

At first the progress along this route was slow and labored, partly because of the primitive status of our knowledge and partly because of the isolation of the different men involved. More recently, progress has accelerated and no small part of this acceleration has been due to the close physical and intellectual proximity of men who might have been, in an earlier time, isolated from each other, not only by space but by the classifications and subclassifications of 'pure' science.

Such interdisciplinary teamwork is being recognized as an important feature of most scientific work today. One element in the success of such teams is the more or less rapid transformation of the originally highly specialized ideas into more general conceptions, followed by the wide dissemination of these more general conceptions throughout the entire scientific community. This result is probably accomplished in a number of ways. The first and most obvious is the mutual stimulation of men working together and by continuous informal discussions gradually evolving, in the group as a whole, new notions and new developments which could hardly be attached to any one individual in the group. This is in contrast to the situation which obtains in work which does not overlap very much into two or more present-day areas of science. Here, the new development may more easily be attached to a single individual.

It is my feeling, however, that the synthesis of a really new conception which involves contributions from two or more distinct disciplines of science requires some sort of union in one mind of the pertinent aspects of several disciplines. The more of the various aspects of science which this man can and does truly encompass, the more likely is a new synthesis to be achieved. In order for this to take place, it is necessary that individuals be not afraid to undertake absorption of the knowledge in areas other than the one in which they were first trained.

This education must be such as to enable the young scientist to explore deeply and well some particular area of natural phenomena. There is no substitute for this sort of concentrated activity and concentration of thought. However, it must be accompanied by the conviction that the student is free to follow, and, in fact, has the duty to follow, the exploration of any natural phenomena into whatever area the light may lead him. In this way will the creation of new horizons overlapping existing divisions of science be encouraged. Without it, we will be limited to the classifications and subdivisions of science developed during the nineteenth and early twentieth centuries, and our thoughts, conceptions, and even practical developments will be circumscribed by the very words and modes of expression which each scientific subdivision of today tends to use.

While the internal walls within the house of science are slowly crumbling, here and there, so that the individual 'purities' are fading, assistance and reconstruction in this is required. This is only part of the much larger problem of bringing back together the various larger subdivisions of human knowledge, particularly of recognizing the place of science in the intellectual activity of man.

It is here that the greater 'impurity' lies. We have been prone to think of science primarily as the birthplace of technology and the child of human need. It is not uncommon to find individuals and organizations justifying their scientific activities in terms of its application, that is, its so-called 'practical' or technological values. We find this kind of justification made on two quite different, but related, levels.

For example, the popular writer for the newspapers and magazines in discussing with the scientific worker the nature of his discoveries will invariably seek to find what he calls the 'useful' application of this discovery, and by 'useful' he means: How can it be utilized to increase the physical ease of the human environment? He is convinced that his readers, that is, the popular readers, have this uppermost in their minds and will read only those stories which contain some elements of material comfort in them. The other level which is based on a similar conviction is that our public legislators from whom a very large fraction of the money to support scientific activities must now come, are moved only by the 'practical' values that they might directly see as a result of their appropriations.

In both these conceptions, the protagonists have overlooked the fact that it has been the great new truths resulting from the activities of scientists as curious human beings that have produced the great transformations which have taken place in the last half dozen centuries in man's view of himself and his place in the universe. Keppler's concern to understand the motion of the heavenly bodies led him to follow Copernicus in putting the sun in the center of our immediate region of space. The earth then became one of the smaller bodies rotating about it, and thus man's home was finally displaced from its central position in the heavens which it had long occupied. This contributed to a profound change in man's concept of his place. Darwin's formulation of evolution in terms of natural selection again placed man in a new relation to life itself which has significantly affected all of his thinking and is still one of the central themes influencing not only the philosophers but the practical politicians as well, not to mention the scientists themselves!

I have selected only two of the most obvious and oustanding scientific truths which have had the most profound and direct influence on our daily intellectual lives. This is continuing to-day in many small as well as large ways. For example, our knowledge of the mechanism of brain structure and function on all levels, including the molecular, is increasing. I have no doubt but what this will have a profound effect upon our present concept of what the nature of consciousness and self-consciousness really is. And this has not yet mentioned what the so-called 'practical' effect of such knowledge might be in the form of either new machines, or the manipulation of man's mind.

Perhaps the most immediate and pressing example of an iminent scientific development whose various effects on our lives can at least be imagined is the impending detailed knowledge of the molecular basis of heredity which we will soon have. In fact, we already have a good deal of it. By this I mean we already know a good deal about the way in which information concerning the construction of a living organism is handed on from generation to generation on a molecular level.

We are fairly confident that this information is in the form of a linear array of only four letters, strung along as though they were on a tape. The whole message for a living organism will be billions of letters long, depending on the complexity of the organism. We can already take fragments of these tapes from one type of an organism and use them to transform another type. We are about to learn how to read the individual letters of these fragments for their smallest bits and pieces of information.

We will shortly be able to use pre-formed bits of this tape, suitably chosen, to control virus infection. Very likely a similar process will be involved in the control ofthe cellular genetic accidents which give rise to cander. It will not be long before we will be able to repair by this means congenital metabolic accidents which at present we are helpless to treat. One can foresee the time when fragments of these information-bearing tapes (the DNA or RNA fragments) will be susceptible to laboratory synthesis.

I think it is clear that we will in the not too distant future be able to 'tamper' with the hereditary mechanism, not only for the primitive microorgansisms but for more highly developed organisms as well, and how we 'tamper' will be a matter of grave concern to us all. Both the immediate and long range future of our country and of mankind is dependent upon decisions on the way we use the fruits of this new knowledge.

If mankind is to survive, the men who make these decisions must be men of broad background. As the chemist must now combine knowledge in fields other than his own, so also must the statesman, businessman and the individual citizen combine basic understanding of science with the humanistic areas of knowledge. The need is pressing and immediate, for we have before us now the requirement for a decision on a course of action probably more profound and far reaching in its consequences than that which faced the statesmen of the world following the discovery of nuclear fission in 1939 and the creation of the first nuclear explosives only six years later. The 'privilege' of 'tampering with heredity' is about to be given to us.

While we cannot predict at this stage the precise nature of the political and social consequences of such changes, that such changes will be profound I have no doubt, and we must be prepared for them on the broadest possible base. Along with scientific specializations, the myth has grown that only a scientist can understand science, and that only children who show promise of becoming scientists need be trained in the fundamental knowledge of science. But only consider for a moment the future of your own progeny if the knowledge made available by science is written into law by legislators who have no way of understanding the implications of that which they legislate.

Only consider the dilemma of the statesmen who were forced to make the initial decisions regarding the first atomic bomb. The scientists who developed the technical information which led to the production of the bomb were forced into sociological decisions of the implication of the use of this new scientific knowledge. The statesmen, equally, were forced into basic, if elementary, understanding of the nature of this new power. The discussions of implications from both the scientific and humanitarian view have occupied world attention for the past twenty-five years.

Let us suppose, for example, that certain legislation concerning an elementary human need is under consideration. During the course of that consideration, the announcement appears that all men born in the west will henceforth have purple eyes if that legislation is enacted. What, then, would be the effect on the legislative decision of such an announcement? Purposely, of course, the example is ludicrous, but one may extrapolate into other areas.

Thus, it is apparent that for the welfare of mankind, scientists must understand the basic knowledge of other fields than their own, and, in addition, must understand the world about them in terms of the humanist as well. And, conversely, the student of the humanities must understand the interrelationships of his own specialty (for example, of urban planning, with the humanitarian, or aesthetic, provisions for peace of mind and of environment) as well as the relationship of his specialty to new knowledge advanced in the area of science.

This is another of the facets of the justification that science must be returned to its proper place as one of the essential components of a liberal education together with the humanistic, aesthetic and literary arts. And in the final analysis science is in the curriculum because it constitutes one of the three or four principal ways that mankind has evolved, up til now, of taking a view of the world around him.

SUMMARY

Once, to many scholars, 'pure' science was the Elysian field, where a biologist could safely spend his lifetime untouched by the physicist, or the chemist. This was true for each branch of natural human knowledge, and this was necessary for the detailed exploration and description of our world. Now so much has been learned in so many artificially defined areas of knowledge that the chemist may not spend his life studying 'pure chemistry' but must be influenced in the comprehension of any problem by the knowledge amassed by the physical scientist, on the one hand, and the biologist, on the other.

A greater impurity, however, lies in the fact that science is not only the birthplace of technology and the child of human need but also a prime progenitor of the great transformations in man's view of himself and his place in the universe which have taken place in the last half dozen centuries and which are due for even greater transformation. Both the immediate and the long range future of our country and of mankind is dependent upon decisions of how we use the fruits of this changing knowledge.

If mankind is to survive, the men who make these decisions must be men of broad background. As the chemist must now combine the knowledge in fields other than his own, so also must the statesman, the businessman, and the individual citizen combine basic understanding of science with the humanistic areas of knowledge. The need is pressing and immediate, for we have before us now the requirement for a decision on a course of action probably more profound and far reaching in its consequences than that which faced the statesmen of the world following the discovery of nuclear fission in 1939 and the creation of the first nuclear explosives only six years later. The 'privilege' of 'tampering with heredity' is about to be given to us.